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PHYSICAL ASPECTS
OF
TORONTO HARBOUR

APRIL 1978

Ministry
of the
Environment
Ontario

The Honourable
Harry C. Parrott, D.D.S.,
Minister

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Deputy Minister

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PHYSICAL ASPECTS
OF
TORONTO HARBOUR

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PHYSICAL ASPECTS OF TORONTO HARBOUR

SUMMARY

Current meters have been operated in both gaps from 1972 to 1975 and at an inner harbour location during 1975. In the West Gap, the resultant currents were going into the inner harbour while in the East Gap, the water movements were from the inner harbour to the lake. On an average, faster currents were observed in the East Gap compared to the West Gap.

During September and October 1975, through the gaps only, the average inflow to the inner harbour was 3.3×10^6 $m^3.d^{-1}$ (8% of inner harbour volume) while the outflow was 1.6×10^6 $m^3.d^{-1}$ (4% of the inner harbour volume). During the same period the average inflow from Don River was 0.4×10^6 $m^3.d^{-1}$ (1% of inner harbour volume) and outflow from Hearn G.S. was 2.6×10^6 $m^3.d^{-1}$ (6% of inner harbour volume). The total daily exchange of the inner harbour amounted to 19% of its volume. The residence time of the inner harbour was computed to be 9.6 days. Smaller residence time means better assimilative capacity of the water body.

PHYSICAL ASPECTS OF TORONTO HARBOUR

INTRODUCTION

Toronto Harbour on Lake Ontario consists of a natural inner harbour and a newly-constructed outer harbour (see Figure 1). The outer harbour has been formed by the construction of an east headland by the Toronto Harbour Commission. The mainland forms the north shore of the inner harbour, and Toronto Islands bound it along the rest of the perimeter. The inner harbour is connected to Lake Ontario by two channels, namely the East Gap and the West Gap. The inner harbour has a water surface area of 4.8×10^6 m^2; water volume 4.1×10^7 m^3 with a mean depth of 8.5 m. The average cross-sectional area of the East Gap was 752 m^2 while that of the West Gap was 1272 m^2 during 1973.

Because of the changes in the shoreline of the harbour, industrial loadings, stormwater overflows and Don River loadings, a predictive water quality model (Poulton, 1977a) capable of representing the effects of alterations of the shoreline, changes in waste discharge and harbour volume, is needed. Harbour circulation, water chemistry and water movements are essential inputs for this model. The water chemistry results have been separately reported (Poulton, 1977b). It was shown that the currents in the West Gap correlated with turbidity and conductivity although the variations in chemistry parameters observed were small. These results confirmed the visual observations that high currents carry large amounts of suspended solids. Current meters have been operated in both gaps since 1972 and in the inner harbour in 1975. This report presents the current meter operations and data analysis from 1972 to 1975.

METHOD

Current instruments (self-recording and submersible type) were operated in the inner harbour and the two gaps at locations shown in Figure 1. Table 1 lists the details of the instrument operations.

All instruments were calibrated in the laboratory and set to record every 10 minutes except Geodyne 102 at location 124 which was set to record every 20 minutes. All Plessey instruments recorded current speed (averaged over 10 min), direction and water temperature every 10 min. The Geodyne 102 recorded current speed and direction averaged over 40 sec after every 20 min at location 124 and every 10 min at location 129.

DATA ANALYSIS

All data were smoothed using the binomial weights (see Appendix I) and then partitioned into monthly records at each location. Standard statistical analyses were employed to compute the two-dimensional frequency of occurrence of current magnitudes and directions for each data set (see Appendix I, Tables 1.01 to 1.22). Table 2 summarizes the statistical results of the currents. One dimensional frequencies of occurrence of water temperatures and the mean and standard deviations were computed for all records with temperature data. The results of water temperature frequencies are summarized in Table 3.

In order to understand the underlying physical processes responsible for the generation of currents, the current velocity data were subjected to time variance spectral analyses. In the East or West Gaps, the data were first resolved along and across the respective gap axes and averaged over one hour. At the harbour location (129), the data were resolved along the north-south and east-west axes and averaged over one hour. This produced two scalar series (along or N-S and across or E-W) for each velocity vector series.

The hourly scalar series were then subjected to the autospectral analyses employing mathematical techniques (see Appendix 1) to produce smooth spectral estimates. Significant peaks were then determined (80, 95 and 99 percent confidence level) by utilizing the degrees of freedom (see Appendix 1) and Figure 1.01. As the spectral analysis of the hourly averaged series with 60 lags is restricted to periodicities greater than 2 h, the data in the two gaps for 1973 and 1975 were reanalyzed using 20 min. averages instead of the hourly averages (see Table 4). The revised analysis did produce the expected shorter periodicities.

Using the concurrent data from a recording current instrument in each gap, the mass exchanges between the inner harbour and the lake, were estimated. Obviously a continuously recording type velocity depth profiling instrument would produce better estimates. However, such an instrument does not exist. Manual measurements would have to be taken at least every two hours (see Table 4) to be meaningful. In the opinion of the author, the present method produces the best statistical exchange estimate.

The current speeds were resolved along the channel axis and then computer plotted to determine the flow reversal pattern (see Figure 2). Examination of computer plots showed that the flow persisted in one direction for 1-8 days followed by flow reversal for a short period of up to 3 h. This pattern was exhibited in both the East and West gaps and is in contrast to the frequent flow reversals every 1-3 h in Burlington Canal (Kohli, 1977). As the flows in East and West Gaps persisted in one direction for many days, the critical excursion distance criterion for the single channel harbour (Kohli, 1977) could not be applied to the two channel system of Toronto Harbour where water predominantly enters the harbour from West Gap and leaves through the East Gap. As a further check, changes in the critical distances did not result in any significant change in the estimated flows. Thus, average daily flows (into and out of Toronto Harbour) were computed for September and October 1975 and these are presented in Figures 3 and 4 together with the corresponding flows from Don River and through the Hearn Generating Station.

DISCUSSION

Figure 1 shows the monthly resultant velocity vectors for the 1972-75 study period. It is apparent that the net water circulation was consistently from west to east. Monthly resultant currents varied from 1.4 to 17.2 $cm.s^{-1}$ (East Gap) and 1.1 to 7.1 $cm.s^{-1}$ (West Gap) - see Figure 1 and Table 1. The arithmetic average speed ranged from 2.4 to 29.8 $cm.s^{-1}$ (East Gap) and 2.1 to 8.4 $cm.s^{-1}$ (West Gap). The East Gap registered maximum speeds of 15.3 to 303.0 $cm.s^{-1}$ while the West Gap recorded maximum speeds of 20.7 to 52.1 $cm.s^{-1}$. Faster speeds of up to 300 $cm.s^{-1}$ as recorded in the East Gap are possible in such restricted channels (van de Kreeke, 1976), the very high currents over short periods may be due to ship movement. These results are similar (excluding the three fastest current periods) to the currents in Burlington Canal (Hamilton Harbour) where the resultant currents varied from 1.8 to 3.3, arithmetic averages ranged between 7.9 and 8.2, and maximum recorded currents were about 45 $cm.s^{-1}$ (Kohli, 1977).

At the inner harbour location (129), the resultant currents varied from 1.1 to 2.8 $cm.s^{-1}$, arithmetic average speed ranged between 2.5 and 4.2 $cm.s^{-1}$. These results are similar to the currents in Hamilton Harbour (Kohli, 1978) where resultant currents ranged from 0.5 to 4.5 $cm.s^{-1}$ while the arithmetic average of currents varied from 1.0 to 6.9 $cm.s^{-1}$.

Water temperatures were recorded at different locations between the months of July and November. The monthly mean temperatures varied from 6.24 (November) to 20.70°C (September) with standard deviations ranging from 0.54 to 3.10°C. The minimum standard deviation of water temperatures was found at location 122 during September 1972 while the maximum standard deviation occurred at the same location during October 1972.

Figures 3 and 4 show the daily flows into and out of the inner harbour during September and October 1975 respectively. The average flow (through the two gaps) from the lake to the inner harbour varied from 2.9 -3.7 x 10^6 $m^3.d^{-1}$ while that in the opposite direction was 1.6 x 10^6 $m^3.d^{-1}$ during the two months. This accounted for the daily exchange (through the gaps only) of 11% (Sep 75) and 13% (Oct 75) of the harbour volume. The total daily exchange through the gaps, Hearn Generating Station and Don River was 19% of the harbour volume. Thus the residence time of the harbour was 9.6 days based on total outflow from the harbour.

In order to achieve mass balance of the harbour, 1.01 x 10^6 (Sep 75) and 0.12 x 10^6 (Oct 75) $m^3.d^{-1}$ must be attributed to rain and other unknown sources. This unknown flow can actually cause water levels in the harbour to fluctuate by 0.03 to 0.20 m per day during these two months. The change in the elevation of harbour water level causes change in the potential energy of the harbour. The balance between the harbour potential energy and the kinetic energy of flow through the connecting channels is responsible for the Helmholtz resonance. Freeman et al (1974) computed the Helmholtz mode of Toronto Harbour as 1.7, 1.4 and 1.1 h and these were observed as significant periods in the spectral analysis (see Table 4). As the Hearn G.S. with an average intake of 2.64 x 10^6 $m^3.d^{-1}$ (which is not returned to the inner harbour but discharged to the outer harbour) could theoretically cause the water level in the harbour to fluctuate by 0.5 m in one day, this may also affect the Helmholtz resonance. Such effects, if any, could not be detected with the present data.

The total daily exchange of water in Toronto Harbour (through the two gaps only) is about twice that in Hamilton Harbour (Kohli, 1977). It is about 12% of the Toronto inner harbour volume. The average daily flow through the Hearn G.S. and Don River is respectively about 6% and 1% of the inner harbour volume. The larger exchange in Toronto Harbour may be attributed to the two connecting channels (compared to a single channel at Hamilton Harbour), Hearn G.S. water intake, Don River inflow and the smaller water depth in the harbour. Helmholtz resonance also increases the water exchange.

The Central Waterfront Planning Committee (CWPC, 1976) found the total daily inflow of 9.04×10^6 $m^3.d^{-1}$ and the outflow of 6.67×10^6 $m^3.d^{-1}$ through the two gaps (see Figure 5). These are, respectively, about 3 and 4 times larger than the corresponding flows computed for the present study. Larger flows by CWPC (1976) may be due to their computational method based on the average current speed through the gaps. The present excursion-episode method (Kohli, 1977) deletes the short term flows which may not clear the East and West Gaps and is, therefore considered a better method.

The major statistically significant spectal periods occurring in the harbour and the two gaps are summarized in Table 4. The lakewide periodicities (17.1, 15.0, 12.0, 9.3, 9.2, 8.0, 5.7, 5.2 and 5.0 h) were found in the currents in the two gaps. The lakewide seiches are responsible for 17.1 and 15.0 h periods while the influence of lunar tide, was observed in the 12.0 h periods.

Rao and Schwab (1974) calculated the theoretical lowest six modes as 5.10, 3.11, 2.31, 1.87, 1.78 and 1.45 h for lake Ontario. Rockwell (1966) obtained the lowest five modes of oscillations as 4.91, 2.97, 2.15, 1.63 and 1.29 h for Lake Ontario. These lower modes of oscillation were observed in the present study (see Table 4). The presence of these lower oscillation modes may be attributed to the local shore geometry. These phenomena are responsible for the variability of the currents.

Spectral analysis of 60 min. averaged data (with 60 lags) could not pick up periodicities less than 2 h. Therefore, the data for 1973 and 1975 were averaged over 20 min. and then subjected to the spectral analysis. Such an analysis picked up significant periods down to 0.8 h. Freeman et al (1974) estimated Helmholtz modes of Toronto Harbour to be 1.7 h (East Gap), 1.4 h (West Gap), and 1.1 h (two channel). Helmholtz periods of 1.7, 1.4 and 1.1 h are found in Table 4. The presence of Helmholtz modes in the data may be partly responsible for the exchange through the two gaps.

The presence of lakewide periodicities, short periods due to local effects, and the Helmholtz periods confirms the general validity of the current meter data.

CONCLUSIONS

Between 1972 and 1975, the net water circulation was dominantly from west to east. On an average, faster currents were observed in the East Gap compared to the West Gap. This may be attributed to smaller cross-sectional area of the East Gap compared with that of the West Gap.

Based on the limited data at a single point in each gap, water exchange was computed. The average inflow through the two gaps was 2.9-3.7 x 10^6 $m^3.d^{-1}$ while the outflow was 1.6 x 10^6 $m^3.d^{-1}$ (additional outflow from the Hearn G.S. was 2.6-2.7 x 10^6 $m^3.d^{-1}$). The total water exchanged through the two gaps was 4.6-5.3 x 10^6 $m^3.d^{-1}$ or about twice the total exchange through the Burlington Canal in Hamilton Harbour. This larger exchange may be partly due to the presence of two channels in Toronto Harbour, Hearn G.S. intake, Don River inflow and smaller harbour depth.

Central Waterfront Planning Committee (1976) published flow estimates through the gaps which are 3 to 4 times larger than the corresponding results of the present study. CWPC's larger estimates were based on cruder analysis.

The harbour residence time of 9.6 days is an indicator of the assimilative capacity of the inner harbour.

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TABLE 1: Current Meter Operations, Toronto Harbour, 1972-75

Location Code	Instrument Type	Instrument from Bottom (m)	Water Depth (m)	Period of Operation	
				From	To
121	P*	2.1	6.1	21 Sep 72	19 Nov 72
122	P	4.0	6.1	21 Sep 72	25 Oct 72
123	P	3.4	6.1	27 Jul 73	7 Sep 73
124	G**	1.2	7.3	27 Jul 73	21 Sep 73
125	P	3.4	6.7	24 Sep 75	26 Nov 75
126	P	4.9	9.8	24 Sep 75	12 Nov 75
129	G	2.4	7.9	24 Sep 75	13 Dec 75

* Plessey M021
**Geodyne 102

TABLE 2: Summary of Current Meter Results, Toronto Harbour, Lake Ontario, 1972-75

	LOCATION (East Gap)								
	121				122		123		
	PERIOD								
	Sep 72	Oct 72A*	Oct 72B*	Nov 72	Sep 72	Oct 72	Jul 73	Aug 73	Sep 73
Resultant direction coming from 0° as North	336	330	332	316	311	322	335	328	312
Resultant Speed cm.s^{-1}	1.35	8.21	3.87	5.09	4.86	17.22	1.93	0.68	1.54
Average Speed cm.s^{-1}	3.16	10.07	7.23	9.84	21.60	29.75	7.92	4.74	4.02
Maximum Speed cm.s^{-1}	32.51	41.14	33.75	37.61	175.62	302.98	24.11	96.77	33.56
Persistence Factor	0.43	0.82	0.53	0.52	0.22	0.58	0.24	0.14	0.38
Percentage of negligible** speed (% of recording period)	48	1	2	2	11	1	1	9	15
Percentage of time going in direction of resultant	33	42	34	21	55	51	12	12	29
Total Number of Readings	1440	2175	2160	2677	1440	3476	720	4464	885
Interval of readings (mins)	10	10	10	10	10	10	10	10	10

*Oct 72A (1 to 16 Oct 1972)
Oct 72B (17 to 31 Oct 1972)
**<0.3 cm.s^{-1}

TABLE 2 (continued)

	LOCATION												
	124 (West Gap)			125 (East Gap)			126 (West Gap)			129 (Harbour)			
	Jul 73	Aug 73	Sep 73	Sep 75	Oct 75	Nov 75	Sep 75	Oct 75	Nov 75	Sep 75	Oct 75	Nov 75	Dec 75
Resultant direction coming from 0° as North	242	241	241	311	313	125	242	243	244	58	250	253	249
Resultant Speed $cm.s^{-1}$	2.60	1.46	2.79	1.71	2.23	2.02	2.90	4.55	7.09	1.13	1.40	2.38	2.84
Average speed $cm.s^{-1}$	4.00	2.06	3.22	3.09	3.67	2.39	6.58	7.06	8.37	3.82	2.52	3.58	4.17
Maximum speed $cm.s^{-1}$	43.67	39.66	52.06	15.31	26.18	26.71	20.70	25.05	40.39	35.59	38.97	39.70	39.98
Persistence Factor	0.65	0.71	0.87	0.55	0.61	0.85	0.44	0.64	0.85	0.30	0.56	0.67	0.68
Percentage of negligible** speed (% of recording period)	33	39	29	9	6	26	3	2	1	16	32	34	18
Percentage of time going in direction of resultant	37	37	43	28	36	29	33	36	40	10	32	32	33
Total number of readings	360	2230	1455	1008	4464	3694	1008	4464	1626	504	2232	2160	875
Interval of readings (mins)	20	20	20	10	10	10	10	10	10	10	10	10	10

**<0.3 $cm.s^{-1}$

TABLE 3: Temperature Frequency, Toronto Harbour, Lake Ontario (Percentage of Occurrence)

TEMPERATURE RANGE °C	LOCATION 121				122		123			125			126		
PERIOD	Sep72	Oct72A	Oct72B	Nov72	Sep72	Oct72	Jul73	Aug73	Sep73	Sep75	Oct75	Nov75	Sep75	Oct75	Nov75
0.00-5.99			14.20	37.64										2.57	
6.00-6.99			55.68	52.38		8.68								2.30	5.19
7.00-7.99			15.63	8.62		29.34						2.80	3.57	12.60	0.74
8.00-8.99			12.22	1.36		12.15						10.03	4.76	17.75	54.81
9.00-9.99		8.29	0.57			6.94						23.68	6.55	35.91	37.78
10.00-10.99		20.17	1.70			6.08						10.86	33.93	22.90	1.48
11.00-11.99		11.05				6.77					2.16	5.43	12.50	5.42	
12.00-12.99	24.69	7.73				5.03		0.41		11.38	10.65	27.63	36.31	0.41	
13.00-13.99	64.44	33.98			10.04	3.13		0.95		22.75	32.21	19.57	2.38	0.14	
14.00-14.99	10.88	18.23			66.53	11.63		1.49		14.97	47.30				
15.00-15.99		0.55			23.43	8.68		3.11		31.14	3.77				
16.00-16.99						1.56	3.39	7.30		19.76	3.77				
17.00-17.99							6.78	9.05			0.13				
18.00-18.99							20.34	12.43	4.11						
19.00-19.99							14.41	12.70	21.23						
20.00-20.99							44.92	22.97	35.62						
21.00-21.99							10.17	10.14	15.75						
22.00-22.99								12.57	18.49						
23.00-100.00								6.89	4.11						
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Monthly Mean	13.41	12.47	6.87	6.24	14.71	10.23	19.65	19.75	20.70	14.80	14.00	11.11	11.25	9.25	8.83
Monthly Std. Dev.	0.60	1.61	0.96	0.65	0.54	3.10	1.19	2.29	2.00	1.29	0.95	1.80	1.35	1.28	0.64

TABLE 4: Summary of Major Spectral Periods (Hours); Autospectra of Currents, Toronto Harbour, Lake Ontario, 1972-75 (80 percent confidence level)

Location	Period	Data Averaged Over (min)	Along Gap	Across Gap
121	Sep 72	60	4.3,3.2,2.1,2.0	10.9*,4.4,3.0
121	Oct 72A	60	4.6,2.9,2.4	15.0*,6.7,4.8,3.8,3.4, 2.9*
121	Oct 72B	60	12.0,7.1,4.8*,3.2,2.4, 2.2	5.6*,2.4,2.1
121	Nov 72	60	4.6*,3.4,2.6*,2.3	8.6,4.8,2.6,2.4
122	Sep 72	60	6.3,2.1	12.0,6.3*,4.1*,3.6, 2.9*,2.4*
122	Oct 72	60	12.0,5.2,3.9,2.6,2.3	15.0*,10.9,7.1*,5.2*, 3.9*,3.3,3.0,2.5*,2.1
123	Aug 73	60	17.1,9.2,4.8	9.3,6.7,2.4
		20	5.0,2.5,1.3*,1.1*,0.8**, 0.7	5.0*,1.9,1.1**
124	Aug 73	60	15.0*,4.6	9.2*,5.2,3.5,2.1
		20	2.0,1.3**,1.1**,0.8**	1.9,1.1**,1.0,0.9*, 0.8*
124	Sep 73	60	5.2**,2.6	None
		20	5.7**,2.8*,1.9,1.1,0.9, 0.8	2.5,1.9,1.1**
125	Sep 75	20	1.1**,1.0**,0.8**	1.7*,1.1**,1.0**, 0.8**
125	Oct 75	60	2.8	None
		20	1.0**,0.8**	1.0**,0.9**
125	Nov 75	60	5.7*	8.0,2.5**
		20	1.0**,0.8**	3.1**,2.1*,1.6**,1.0**
126	Sep 75	20	4.0,1.1**,1.0**,0.8**	3.1,1.3,1.1*,1.0**,0.8
126	Oct 75	60	4.6,2.4	2.4
		20	2.4*,1.3*,1.0**,0.8**	3.6,1.7,1.0**,0.8*,0.7
126	Nov 75	60	None	None
		20	2.1*,1.7,1.3*,1.0**,0.8**	2.0**,1.4,1.1**,0.8**, 0.7**
129	Oct 75	60	14.1,7.5	9.6,7.5*,6.7,5.2,4.2
129	Nov 75	60	12.0	15.0,4.2*

Note: For location 129 only, "Along Gap" is "North-South", while "Across Gap" is "East-West"

*95 percent confidence level

**99 percent confidence level

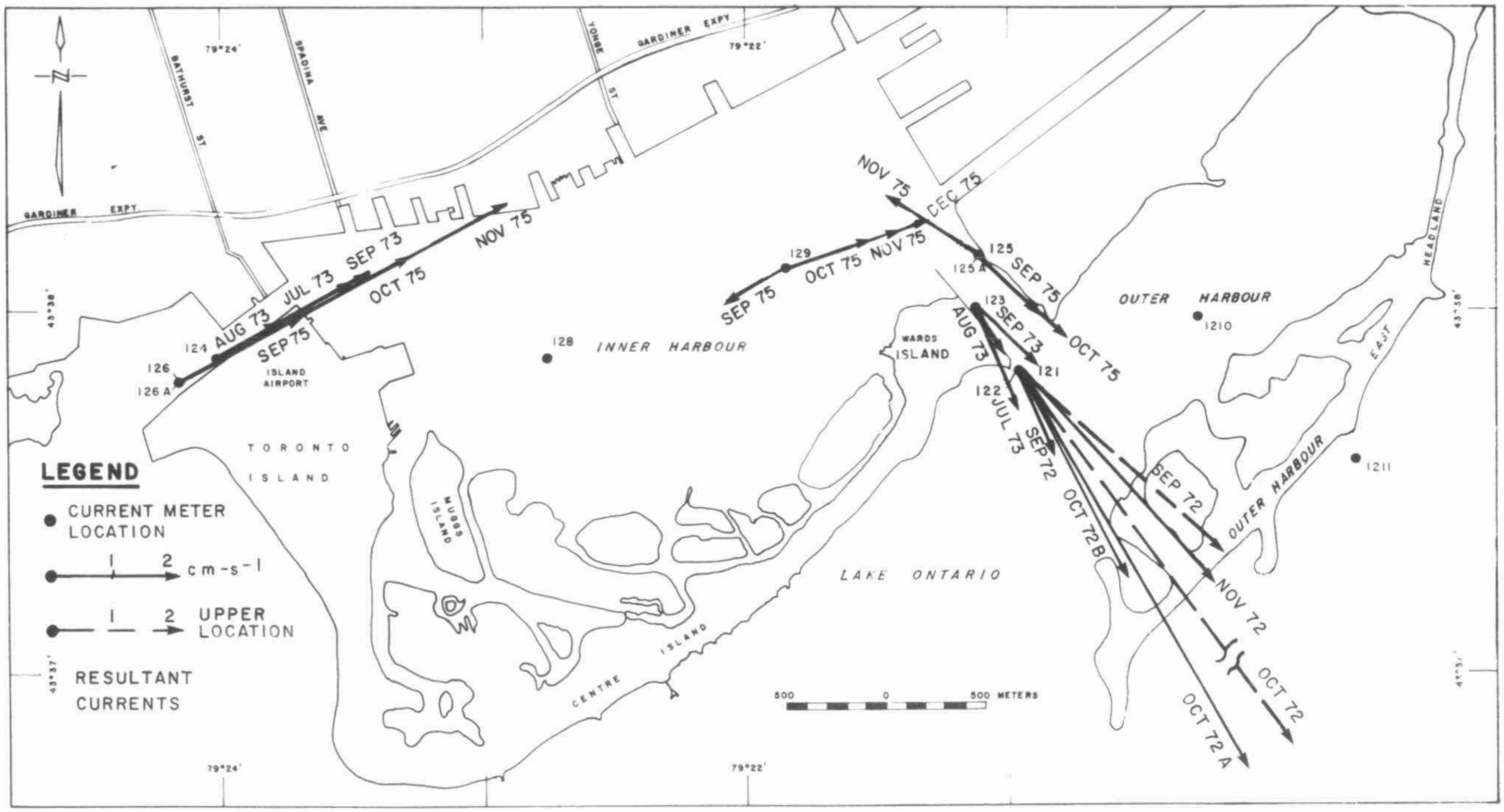

FIGURE 1: RESULTANT CURRENTS, TORONTO HARBOUR, LAKE ONTARIO, 1972 – 1975.

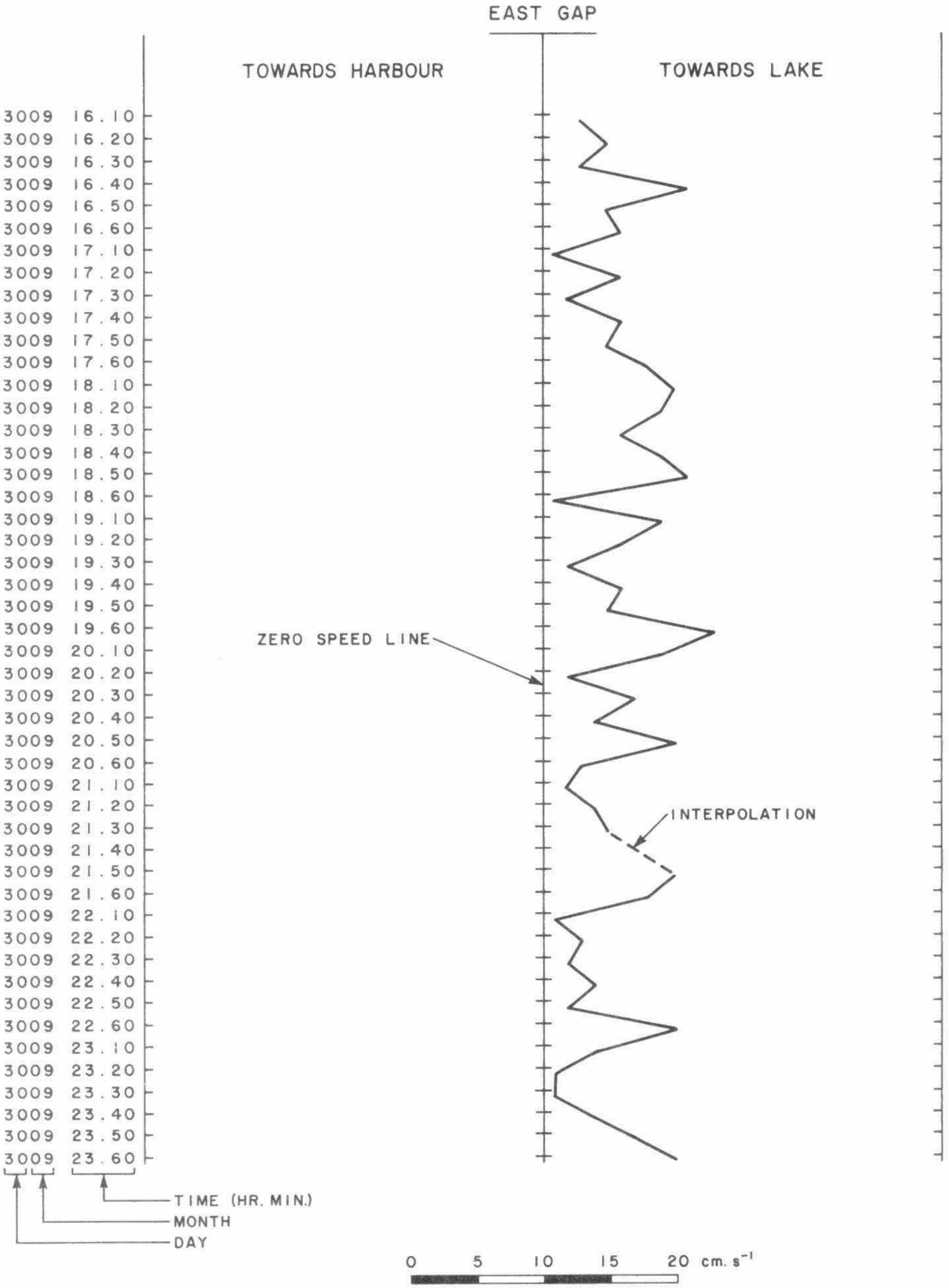

FIGURE 2 - TIME HISTORY OF CURRENTS RESOLVED ALONG EAST GAP TORONTO HARBOUR, LAKE ONTARIO, 1975.

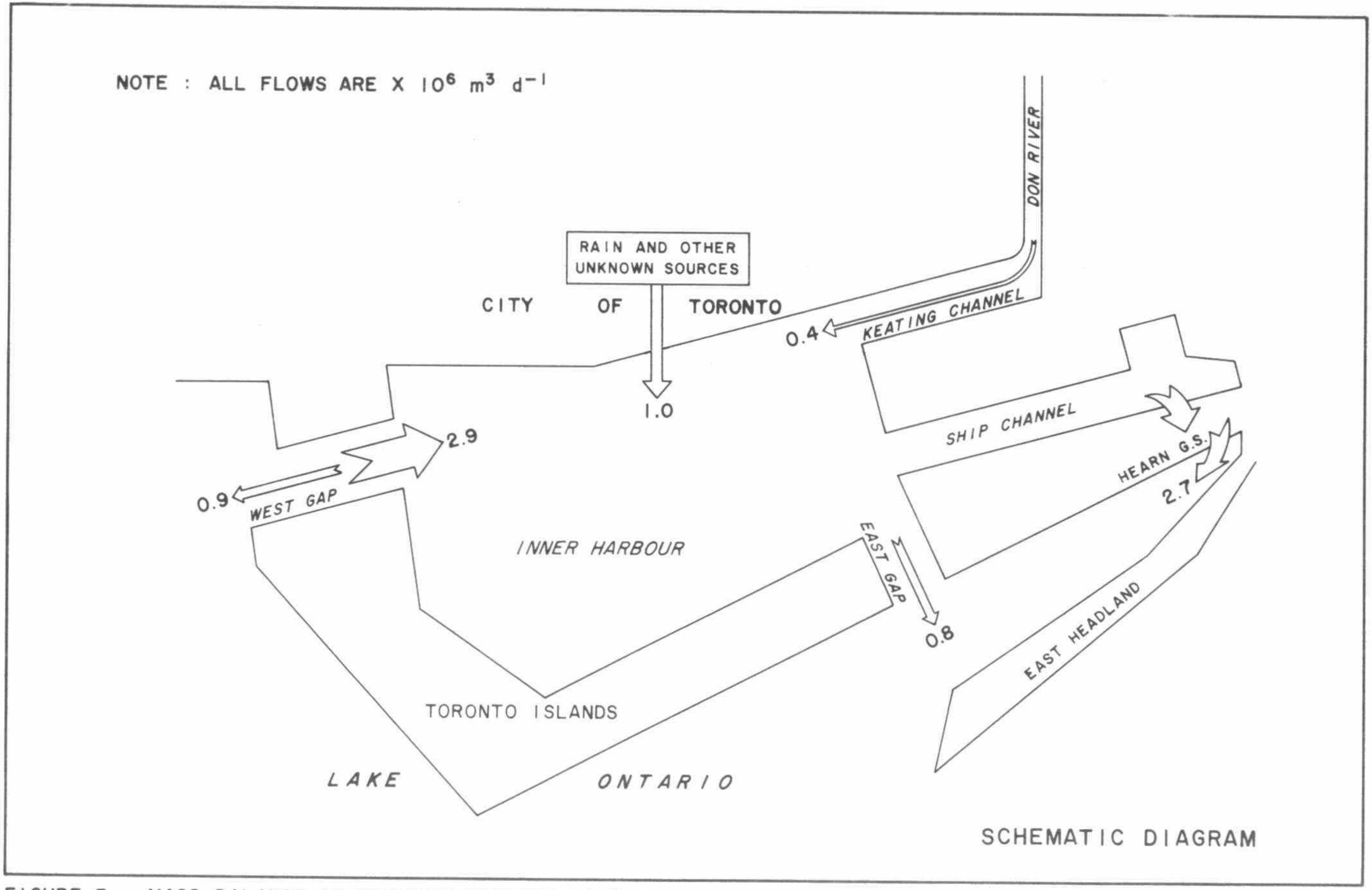

FIGURE 3 - MASS BALANCE OF TORONTO HARBOUR, LAKE ONTARIO, SEPTEMBER 1975.

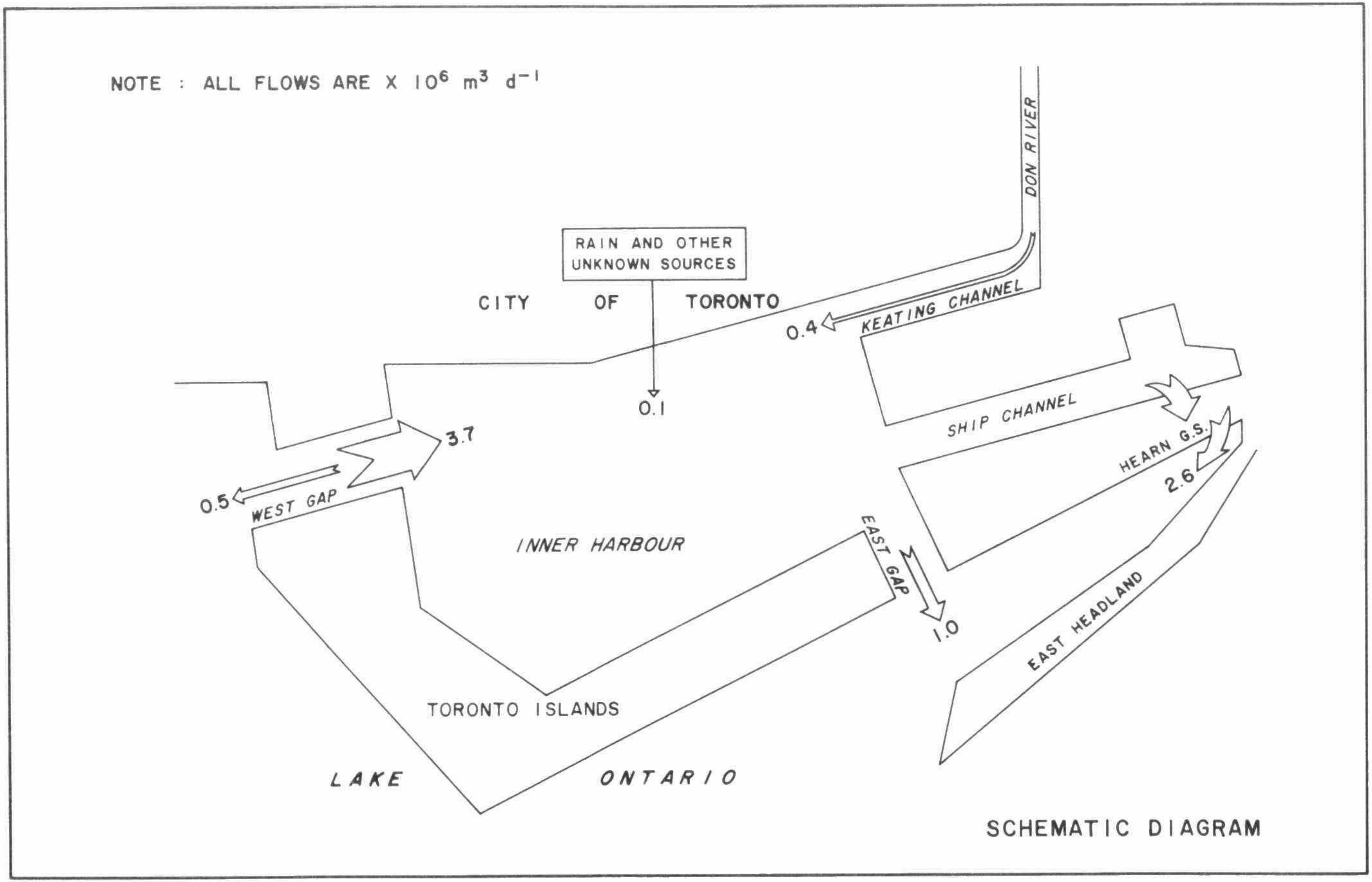

FIGURE 4 - MASS BALANCE OF TORONTO HARBOUR, LAKE ONTARIO, OCTOBER 1975.

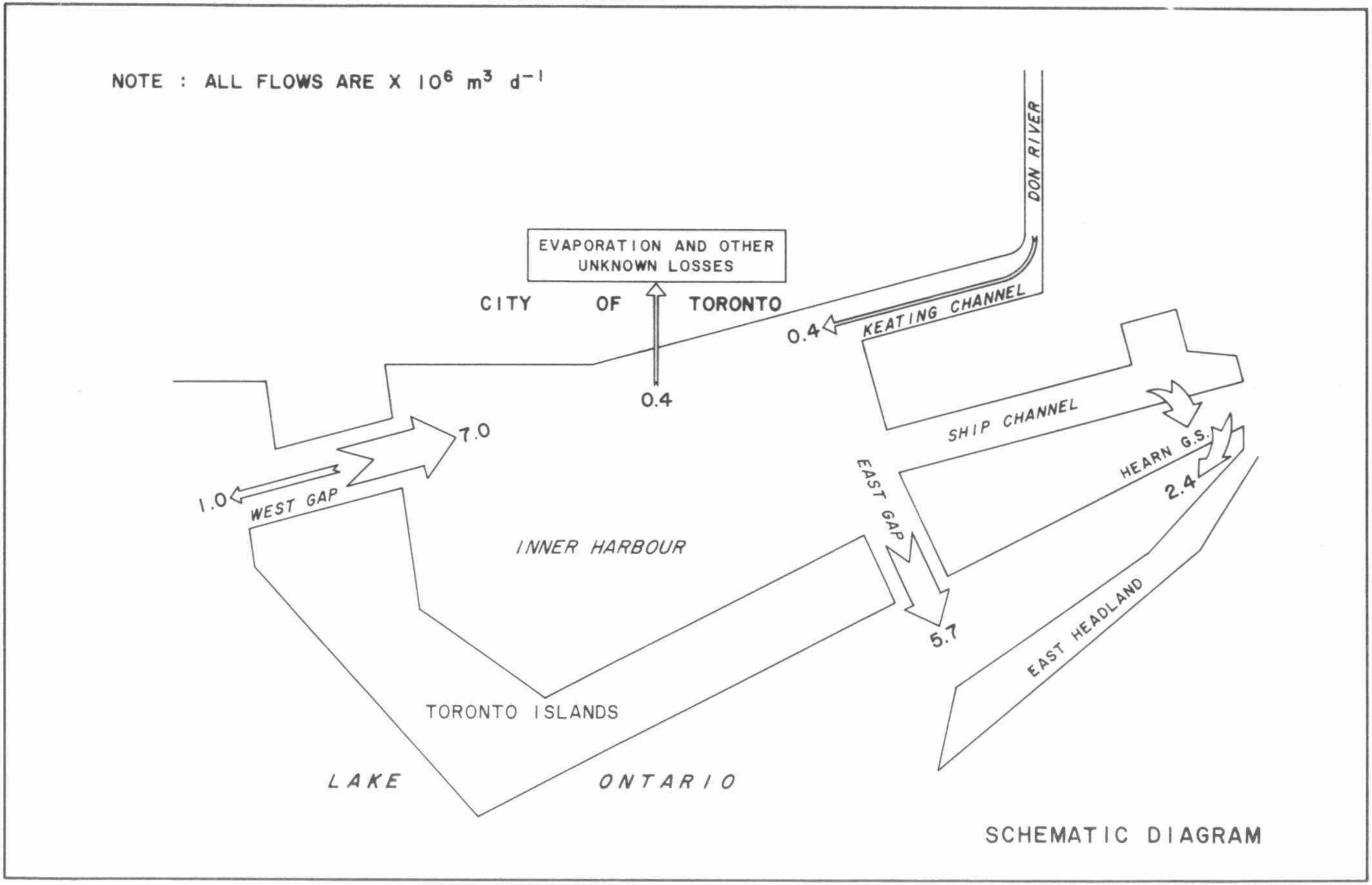

FIGURE 5 – MASS BALANCE OF TORONTO HARBOUR, LAKE ONTARIO.
(AFTER CENTRAL WATERFRONT PLANNING COMMITTEE INFORMATION BASE, 1976.)

APPENDIX 1

The data from all locations were pre-whitened (numerically smoothed) after Blackman and Tukey (1959; p.29, 39, 74) using binomial weights after Panofsky and Brier (1968; p. 150).

Binomial distribution is generally applied to cases when two alternatives are possible, e.g. a coin spun can land with either head or tail. If N coins are spun independently, m heads and (N-m) tails will show up. Smoothing functions can be made to approximate the normal distribution curve by making the weights proportional to the binomial distribution. The smoothing coefficients (C_m) are computed thus:

$$C_m = N!/m!\ (N-m)! \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

For data at 10 to 20 min intervals N=4 produced acceptable binomial coefficients.

The binomial weights (S_m) for smoothing the data series are obtained as follows:

$$S_m = C_m / \sum_{0}^{m} C_m \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Current speed and direction and water temperature data are smoothed as above. However, if the instrument is operated in a channel (e.g. east or west gap), the direction is not smoothed since the water movements in channels are essentially along the channel axis.

The smoothed data are then partitioned into monthly records. For each record, a two-dimensional frequency of occurrence of current speed and direction were computed along with the resultant speed and direction, mean and maximum current speeds and the persistence. The current frequency tables along with the above results are presented in Tables 1.01 and 1.22.

AUTOSPECTRA

Time series can be subjected to spectral analysis to help understand the physics underlying the variations in the time series by comparing the significant periods of time variation with the theoretical values. Statistically significant peaks indicate the likelihood or otherwise of variations with certain average peaks. As a prerequisite for spectral analysis, auto-correlation coefficients of the time series are computed. Auto-correlation coefficients are ordinary correlation coefficients of two members of the time series at different time lags.

Let X_i represent the time series. Auto-correlation coefficients may be computed as (Panofsky and Brier, p. 138):

$$r_\ell = (X_i - \bar{X})(X_{i+\ell} - \bar{X}) / n\sigma^2 \quad .... (3)$$

where r_ℓ is the auto-correlation coefficient for the lag .

$\bar{X}$ is the arithmatic average of the series X_i

n is the length of the series

σ^2 is the variance of the series

Auto-correlation coefficients are utilized to comput the normalized spectrum B_i (Panofsky and Brier, p. 143).

$$B_i(r_o/m)+(2/m)\sum_{\ell=1}^{m-1} \left[r_\ell \cos(\pi i \ell/m) + r_m(-1)^i/m \right. \quad ..(4)$$

Equation (4) results in greatly distorted spectral estimates whenever there are rapid fluctuations in the true spectrum. Spectral estimates are therefore smoothed by Hanning (Blackman and Tukey, 1959, p. 34 and 171) as follows:

$$S_i = 0.25\, B_{i-1} + 0.50\, B_i + 0.25\, B_{i+1} \quad .... (5)$$

where S_i are the smoothed spectral estimates.

In order to determine the statistically significant periods of the spectral analysis the degrees of freedom (ν) associated with the spectrum are computed thus:

$$\nu = (2n - \ell/2)/\ell \qquad \ldots\ldots\ldots\ldots(6)$$

Jenkins and Watts (1968; p. 82) plotted the upper and lower limits for α =0.01, 0.05 and 0.20 and $3 \leq \nu \leq 100$ (see Figure 1.01). The curves can be used to determine an interval within which a spectral peak may be expected to lie on 100(1- α) % of occasions.

REFERENCES

1. Black, R.B. and J.W. Tukey, 1959. The Measurement of Power Spectra. Dover Publications, Inc., New York, 198 p.

2. Panofsky, H.A. and G.W. Brier, 1968. Some Applications of Statistics to Meteorology. The Pennsylvania State University, University Park, Pennsylvania 224 p.

3. Jenkins, G.M. and D.G. Watts, 1968. Spectral Analysis and its Applications. Holden-Day, San Francisco. 525 p.

TABLE 1.01

LOCATION CODE : 1210

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Sep 72

LATITUDE : 79 20 57 W

LONGITUDE : 43 37 50 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	1.87	0.21	0.90	10.83	2.78	0.56	0.97	29.51	47.64
0.31-1.99	0.76	0.07	0.21	5.56	1.25	0.07	0.07	10.00	17.99
2.00-3.99	0.28	0.07	0.0	3.19	0.49	0.0	0.0	4.86	8.89
4.00-5.99	0.21	0.0	0.07	1.94	0.14	0.0	0.0	3.75	6.11
6.00-7.99	0.35	0.07	0.0	1.67	0.07	0.0	0.0	2.57	4.72
8.00-9.99	0.14	0.0	0.14	0.56	0.07	0.0	0.0	2.85	3.75
10.00-32.99	0.76	0.0	0.07	2.36	0.35	0.0	0.0	7.36	10.90
COLUMN SUMS	4.37	0.42	1.39	26.11	5.14	0.62	1.04	60.90	100.00

RESULTANT CURRENT IS 1.35 cm.s^{-1} AT 336° FROM NORTH

MEAN CURRENT IS 3.16 cm.s^{-1}

MAXIMUM CURRENT IS 32.51 cm.s^{-1}

TOTAL NUMBER OF READINGS 1440

PERSISTENCE IS 0.43

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 2.1 m FROM BOTTOM IN 6.1 m OF WATER

TABLE 1.02

LOCATION CODE : 1210
AREA : Toronto Harbour
LAKE : Ontario

PERIOD : Oct 72 A
LATITUDE : 79 20 57 W
LONGITUDE : 43 37 50 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0,0-0.30	0.05	0.0	0.37	0.18	0.18	0.0	0.0	0.32	1.10
0.31-2.99	0.87	0.37	0.55	1.84	0.60	0.37	0.64	5.79	11.03
3.00-5.99	1.15	0.32	0.23	2.30	0.64	0.14	0.28	12.51	17.56
6.00-8.99	1.33	0.18	0.14	3.31	0.55	0.09	0.05	14.11	19.77
9.00-11.99	0.46	0.0	0.09	1.24	0.05	0.05	0.09	14.39	16.37
12.00-14.99	0.14	0.09	0.0	0.74	0.18	0.0	0.0	13.24	14.39
15.00-41.99	0.28	0.0	0.0	0.60	0.14	0.0	0.0	18.76	19.77
COLUMN SUMS	4.28	0.97	1.38	10.21	2.34	0.64	1.06	79.13	100.00

RESULTANT CURRENT IS 8.21 cm.s^{-1} AT 330° FROM NORTH

MEAN CURRENT IS 10.07 cm.s^{-1}

MAXIMUM CURRENT IS 41.14 cm.s^{-1}

TOTAL NUMBER OF READINGS 2175

PERSISTENCE IS 0.82

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 2.1 m FROM BOTTOM IN 6.1 m OF WATER

Ministry of the Environment

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TABLE 1.03

LOCATION CODE : 1210

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Oct 72 B

LATITUDE : 79 20 57 W

LONGITUDE : 43 37 50 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.0	0.19	0.09	0.37	0.05	0.05	0.14	0.65	1.53
0.31-1.99	0.97	0.28	0.65	1.71	0.51	1.11	0.60	5.37	11.20
2.00-3.99	1.39	0.32	1.02	2.78	1.39	0.97	0.65	8.52	17.04
4.00-5.99	1.53	0.32	0.42	3.66	1.53	0.60	0.14	11.30	19.49
6.00-7.99	0.97	0.05	0.28	3.52	0.65	0.28	0.14	8.01	13.89
8.00-9.99	0.42	0.09	0.23	2.41	0.56	0.09	0.09	8.01	11.90
10.00-33.99	1.71	0.37	0.19	3.43	0.46	0.23	0.0	18.56	24.95
COLUMN SUMS	6.99	1.62	2.87	17.87	5.14	3.33	1.76	60.42	100.00

RESULTANT CURRENT IS 3.87 cm.s^{-1} AT 332° FROM NORTH

MEAN CURRENT IS 7.23 cm.s^{-1}

MAXIMUM CURRENT IS 33.75 cm.s^{-1}

TOTAL NUMBER OF READINGS 2160

PERSISTENCE IS 0.53

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 2.1 m FROM BOTTOM IN 6.1 m OF WATER

Ministry of the
Environment

Ontario

TABLE 1.04

LOCATION CODE : 1210

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Nov 72

LATITUDE : 79 20 57 W

LONGITUDE : 43 37 50 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES) 337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.19	0.0	0.04	0.0	0.0	0.04	1.34	0.04	1.64
0.31-2.99	0.49	0.19	0.78	1.05	0.90	0.75	6.13	3.81	14.08
3.00-5.99	0.56	0.26	1.01	2.09	0.60	0.78	6.84	6.13	18.27
6.00-8.99	0.34	0.52	1.05	1.64	0.60	0.41	6.35	7.36	18.27
9.00-11.99	0.45	0.60	0.75	0.97	0.52	0.30	4.26	8.63	16.47
12.00-14.99	0.19	0.60	0.45	0.75	0.19	0.19	2.32	5.98	10.65
15.00-37.99	0.26	2.47	1.12	2.20	0.22	0.41	2.99	10.95	20.62
COLUMN SUMS	2.47	4.63	5.19	8.70	3.03	2.88	30.22	42.88	100.00

RESULTANT CURRENT IS 5.09 cm.s^{-1} AT 316° FROM NORTH

MEAN CURRENT IS 9.84 cm.s^{-1}

MAXIMUM CURRENT IS 37.61 cm.s^{-1}

TOTAL NUMBER OF READINGS 2677

PERSISTENCE IS 0.52

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 2.1 m FROM BOTTOM IN 6.1 m OF WATER

TABLE 1.05

LOCATION CODE : 1220

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Sep 72

LATITUDE : 79 20 57 W

LONGITUDE : 43 37 50 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES) 337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.76	0.21	0.0	3.89	0.97	0.0	0.21	4.72	10.76
0.31-9.99	0.97	0.28	0.07	7.08	1.39	0.21	0.35	13.61	23.96
10.00-19.99	1.46	0.21	0.28	4.03	1.46	0.56	0.56	13.12	21.67
20.00-29.99	1.04	0.07	0.14	4.37	1.46	0.35	0.21	9.65	17.29
30.00-39.99	0.56	0.0	0.07	2.57	0.90	0.62	0.62	7.50	12.85
40.00-49.99	0.69	0.0	0.0	1.67	0.35	0.07	0.76	5.07	8.61
50.00-175.99	0.0	0.0	0.0	2.43	0.0	0.83	0.14	1.46	4.86
COLUMN SUMS	5.49	0.76	0.56	26.04	6.53	2.64	2.85	55.14	100.00

RESULTANT CURRENT IS 4.86 cm.s^{-1} AT 311° FROM NORTH

MEAN CURRENT IS 21.60 cm.s^{-1}

MAXIMUM CURRENT IS 175.62 cm.s^{-1}

TOTAL NUMBER OF READINGS 1440

PERSISTENCE IS 0.22

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 4.0 m FROM BOTTOM IN 6.1 m OF WATER

Ministry of the
Environment

Ontario

TABLE 1.06

LOCATION CODE : 1220

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Oct 72

LATITUDE : 79 20 57 W

LONGITUDE : 43 37 50 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES) 337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.06	0.0	0.0	0.0	0.0	0.0	0.72	0.55	1.32
0.31-15.99	5.41	0.40	1.61	5.58	1.27	0.26	5.03	18.87	38.43
16.00-31.99	4.57	0.20	0.60	5.01	1.27	0.23	2.16	13.87	27.91
32.00-47.99	3.28	0.37	0.23	2.59	0.58	0.0	1.38	10.73	19.16
48.00-63.99	0.58	0.0	0.0	0.66	0.0	0.0	0.46	1.87	3.57
64.00-79.99	0.72	0.0	0.0	0.37	0.0	0.0	0.29	1.35	2.73
80.00-302.99	0.83	0.0	0.0	0.83	0.12	0.0	1.64	3.45	6.88
COLUMN SUMS	15.45	0.98	2.45	15.05	3.22	0.49	11.68	50.69	100.00

RESULTANT CURRENT IS 17.22 cm.s^{-1} AT 322° FROM NORTH

MEAN CURRENT IS 29.75 cm.s^{-1}

MAXIMUM CURRENT IS 302.98 cm.s^{-1}

TOTAL NUMBER OF READINGS 3476

PERSISTENCE IS 0.58

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 4.0 m FROM BOTTOM IN 6.1 m OF WATER

TABLE 1.07

LOCATION CODE : 1230

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Jul 73

LATITUDE : 79 21 08 W

LONGITUDE : 43 37 59 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES) 337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.0	0.0	0.28	0.14	0.0	0.14	0.69	0.0	1.25
0.31-1.99	0.0	0.28	2.22	1.25	0.0	0.14	2.64	0.14	6.67
2.00-3.99	0.14	1.25	6.11	2.22	0.28	0.56	4.58	0.69	15.83
4.00-5.99	0.42	2.78	3.89	2.22	0.28	0.97	5.14	0.69	16.39
6.00-7.99	0.97	2.92	5.28	2.22	0.0	0.69	3.19	1.94	17.22
8.00-9.99	0.56	1.67	1.94	2.22	0.14	0.28	3.06	3.61	13.47
10.00-24.99	1.11	4.03	0.83	3.75	0.42	0.97	3.75	14.31	29.17
COLUMN SUMS	3.19	12.92	20.56	14.03	1.11	3.75	23.06	21.39	100.00

RESULTANT CURRENT IS 1.93 cm.s^{-1} AT 335° FROM NORTH

MEAN CURRENT IS 7.92 cm.s^{-1}

MAXIMUM CURRENT IS 24.11 cm.s^{-1}

TOTAL NUMBER OF READINGS 720

PERSISTENCE IS 0.24

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 3.4 m FROM BOTTOM IN 6.1 m OF WATER

TABLE 1.08

LOCATION CODE : 1230
AREA : Toronto Harbour
LAKE : Ontario

PERIOD : Aug 73
LATITUDE : 79 21 08 W
LONGITUDE : 43 37 59 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES) 337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.07	0.76	2.17	1.52	0.13	0.47	2.93	1.10	9.16
0.31-5.99	0.81	7.06	9.57	11.78	0.87	2.91	13.13	12.68	58.80
6.00-11.99	0.40	4.39	2.60	5.31	0.18	1.05	5.04	8.69	27.67
12.00-17.99	0.0	0.69	0.16	0.74	0.02	0.09	0.67	1.19	3.56
18.00-23.99	0.0	0.07	0.02	0.13	0.0	0.02	0.07	0.13	0.45
24.00-29.99	0.0	0.0	0.04	0.0	0.0	0.0	0.0	0.04	0.09
30.00-96.99	0.0	0.02	0.11	0.02	0.0	0.0	0.02	0.09	0.27
COLUMN SUMS	1.28	12.99	14.67	19.51	1.21	4.55	21.86	23.92	100.00

RESULTANT CURRENT IS 0.68 cm.s^{-1} AT 328° FROM NORTH

MEAN CURRENT IS 4.74 cm.s^{-1}

MAXIMUM CURRENT IS 96.77 cm.s^{-1}

TOTAL NUMBER OF READINGS 4464

PERSISTENCE IS 0.14

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 3.4 m FROM BOTTOM IN 6.1 m OF WATER

TABLE 1.09

LOCATION CODE : 1230

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Sep 73

LATITUDE : 79 21 08 W

LONGITUDE : 43 37 59 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.56	2.37	0.23	1.36	0.79	0.56	1.02	8.14	15.03
0.31-1.99	0.56	3.39	0.23	2.37	0.68	0.11	1.58	13.11	22.03
2.00-3.99	0.56	1.92	0.56	2.60	0.34	0.79	1.36	14.35	22.49
4.00-5.99	0.79	2.03	0.45	2.60	0.23	0.79	0.34	9.27	16.50
6.00-7.99	0.45	2.26	0.11	1.24	0.11	0.11	0.45	7.57	12.32
8.00-9.99	0.0	1.02	0.11	0.68	0.0	0.11	0.11	3.39	5.42
10.00-33.99	0.11	1.13	0.11	1.69	0.11	0.11	0.45	2.49	6.21
COLUMN SUMS	3.05	14.12	1.81	12.54	2.26	2.60	5.31	58.31	100.00

RESULTANT CURRENT IS 1.54 cm.s^{-1} AT 312° FROM NORTH

MEAN CURRENT IS 4.02 cm.s^{-1}

MAXIMUM CURRENT IS 33.56 cm.s^{-1}

TOTAL NUMBER OF READINGS 885

PERSISTENCE IS 0.38

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 3.4 m FROM BOTTOM IN 6.1 m OF WATER

TABLE 1.10

LOCATION CODE : 1240
AREA : Toronto Harbour
LAKE : Ontario

PERIOD : Jul 73
LATITUDE : 79 24 01 W
LONGITUDE : 43 37 51 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.28	6.11	4.17	1.39	2.22	15.28	3.89	0.0	33.33
0.31-2.99	0.28	1.39	0.83	0.0	0.28	13.33	1.67	0.56	18.33
3.00-5.99	0.0	2.22	0.83	0.56	0.0	17.22	2.22	0.28	23.33
6.00-8.99	0.0	1.94	0.28	0.0	0.0	14.17	0.0	0.0	16.39
9.00-11.99	0.0	0.56	0.28	0.0	0.0	3.89	0.56	0.0	5.28
12.00-14.99	0.0	0.56	0.0	0.0	0.0	0.56	0.0	0.0	1.11
15.00-43.99	0.56	0.0	0.0	0.28	0.0	1.39	0.0	0.0	2.22
COLUMN SUMS	1.11	12.78	6.39	2.22	2.50	65.83	8.33	0.83	100.00

RESULTANT CURRENT IS 2.60 cm.s^{-1} AT 242° FROM NORTH

MEAN CURRENT IS 4.00 cm.s^{-1}

MAXIMUM CURRENT IS 43.67 cm.s^{-1}

TOTAL NUMBER OF READINGS 360

PERSISTENCE IS 0.65

READINGS TAKEN EVERY 20 min

INSTRUMENT WAS OPERATED 1.2 m FROM BOTTOM IN 7.3 m OF WATER

TABLE 1.11

LOCATION CODE : 1240

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Aug 73

LATITUDE : 79 24 01 W

LONGITUDE : 43 37 51 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	1.21	6.63	1.93	0.27	0.27	23.21	4.35	1.52	39.38
0.31-2.99	1.08	6.45	2.15	0.18	0.27	20.56	3.23	0.85	34.77
3.00-5.99	0.09	1.84	0.54	0.04	0.13	12.81	0.76	0.13	16.35
6.00-8.99	0.04	0.40	0.40	0.0	0.0	5.78	0.18	0.0	6.81
9.00-11.99	0.04	0.09	0.09	0.0	0.0	1.88	0.0	0.0	2.11
12.00-14.99	0.0	0.0	0.04	0.0	0.0	0.36	0.0	0.0	0.40
15.00-39.99	0.0	0.0	0.0	0.0	0.0	0.18	0.0	0.0	0.18
COLUMN SUMS	2.46	15.41	5.15	0.49	0.67	64.78	8.51	2.51	100.00

RESULTANT CURRENT IS 1.46 cm.s^{-1} AT 241° FROM NORTH

MEAN CURRENT IS 2.06 cm.s^{-1}

MAXIMUM CURRENT IS 39.66 cm.s^{-1}

TOTAL NUMBER OF READINGS 2232

PERSISTENCE IS 0.71

READINGS TAKEN EVERY 20 min

INSTRUMENT WAS OPERATED 1.2 m FROM BOTTOM IN 7.3 m OF WATER

TABLE 1.12

LOCATION CODE : 1240
AREA : Toronto Harbour
LAKE : Ontario

PERIOD : Sep 73
LATITUDE : 79 24 01 W
LONGITUDE : 43 37 51 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.89	1.86	0.69	0.07	0.27	20.00	3.23	1.65	28.66
0.31-2.99	0.55	2.96	1.24	0.14	0.27	22.61	3.37	1.03	32.16
3.00-5.99	0.21	1.37	0.62	0.07	0.00	20.07	0.69	0.14	23.16
6.00-8.99	0.00	0.14	0.27	0.00	0.00	8.66	0.48	0.07	9.62
9.00-11.99	0.00	0.07	0.07	0.00	0.00	3.44	0.07	0.00	3.64
12.00-14.99	0.00	0.00	0.14	0.00	0.00	1.03	0.00	0.00	1.17
15.00-52.99	0.00	0.07	0.00	0.00	0.00	1.44	0.00	0.07	1.58
COLUMN SUMS	1.65	6.46	3.02	0.27	0.55	77.25	7.84	2.96	100.00

RESULTANT CURRENT IS 2.79 cm.s^{-1} AT 241° FROM NORTH

MEAN CURRENT IS 3.22 cm.s^{-1}

MAXIMUM CURRENT IS 52.06 cm.s^{-1}

TOTAL NUMBER OF READINGS 1455

PERSISTENCE IS 0.87

READINGS TAKEN EVERY 20 min

INSTRUMENT WAS OPERATED 1.2 m FROM BOTTOM IN 7.3 m OF WATER

TABLE 1.13

LOCATION CODE : 1250
AREA : Toronto Harbour
LAKE : Ontario

PERIOD : Sep 75
LATITUDE : 79 21 06 W
LONGITUDE : 43 38 09 N

FREQUENCY TABLE

SPEED ($cm.s^{-1}$)	DIRECTION COMING FROM (DEGREES) 337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.10	0.20	5.16	0.89	0.60	0.50	0.89	0.20	8.53
0.31-0.99	1.49	2.18	8.04	0.50	0.60	0.50	1.69	0.60	15.58
1.00-1.99	2.68	1.29	4.17	1.09	0.69	0.10	4.17	3.27	17.46
2.00-2.99	1.29	0.60	2.98	0.99	0.79	0.00	5.75	4.07	16.47
3.00-3.99	0.79	0.40	1.49	0.69	0.20	0.40	4.76	4.46	13.19
4.00-4.99	0.20	0.10	1.29	0.60	0.10	0.00	2.68	4.76	9.72
5.00-15.99	0.60	0.00	1.59	0.89	0.00	0.00	5.06	10.91	19.05
COLUMN SUMS	7.14	4.76	24.70	5.65	2.98	1.49	25.00	28.27	100.00

RESULTANT CURRENT IS 1.71 $cm.s^{-1}$ AT 311° FROM NORTH

MEAN CURRENT IS 3.09 $cm.s^{-1}$

MAXIMUM CURRENT IS 15.31 $cm.s^{-1}$

TOTAL NUMBER OF READINGS 1008

PERSISTENCE IS 0.55

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 3.4 m FROM BOTTOM IN 6.7 m OF WATER

TABLE 1.14

LOCATION CODE : 1250

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Oct 75

LATITUDE : 79 21 06 W

LONGITUDE : 43 38 09 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES) 337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.11	0.09	2.46	0.22	2.04	0.22	0.60	0.11	5.87
0.31-1.99	2.71	2.80	11.90	0.54	2.11	0.43	5.56	3.07	29.10
2.00-3.99	2.91	0.85	6.03	1.01	0.69	0.20	8.20	9.74	29.64
4.00-5.99	0.74	0.13	1.61	0.56	0.29	0.07	4.50	9.34	17.25
6.00-7.99	0.07	0.04	0.47	0.43	0.16	0.04	1.23	6.25	8.69
8.00-9.99	0.02	0.00	0.20	0.25	0.04	0.07	0.65	3.18	4.41
10.00-26.99	0.74	0.00	0.02	0.16	0.07	0.04	0.16	3.85	5.04
COLUMN SUMS	7.30	3.92	22.69	3.16	5.40	1.08	20.90	35.55	100.00

RESULTANT CURRENT IS 2.23 cm.s^{-1} AT 313° FROM NORTH

MEAN CURRENT IS 3.67 cm.s^{-1}

MAXIMUM CURRENT IS 26.18 cm.s^{-1}

TOTAL NUMBER OF READINGS 4464

PERSISTENCE IS 0.61

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 3.4 m FROM BOTTOM IN 6.7 m OF WATER

TABLE 1.15

LOCATION CODE : 1250
AREA : Toronto Harbour
LAKE : Ontario

PERIOD : Nov 75
LATITUDE : 79 21 06 W
LONGITUDE : 43 38 09 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.00-0.30	0.00	0.08	0.32	2.22	23.34	0.38	0.00	0.00	26.34
0.31-1.99	0.00	0.11	2.27	11.13	24.77	0.79	0.00	0.00	39.06
2.00-3.99	0.00	0.14	4.60	7.39	3.82	0.03	0.00	0.00	15.97
4.00-5.99	0.00	0.16	2.92	3.30	0.87	0.00	0.00	0.00	7.26
6.00-7.99	0.03	0.0	1.81	1.81	0.24	0.00	0.00	0.00	3.90
8.00-9.99	0.00	0.16	1.33	1.14	0.05	0.00	0.00	0.00	2.68
10.00-26.99	0.05	1.06	1.95	1.73	0.00	0.00	0.00	0.00	4.79
COLUMN SUMS	0.08	1.71	15.21	28.72	53.09	1.19	0.00	0.00	100.00

RESULTANT CURRENT IS 2.02 cm.s^{-1} AT 125° FROM NORTH

MEAN CURRENT IS 2.39 cm.s^{-1}

MAXIMUM CURRENT IS 26.71 cm.s^{-1}

TOTAL NUMBER OF READINGS 3694

PERSISTENCE IS 0.85

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 3.4 m FROM BOTTOM IN 6.7 m OF WATER

TABLE 1.16

LOCATION CODE : 1260

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Sep 75

LATITUDE : 79 24 09 W

LONGITUDE : 43 37 48 N

FREQUENCY TABLE

	DIRECTION COMING FROM (DEGREES)								
SPEED (cm.s^{-1})	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.50	0.40	0.20	0.00	0.00	0.50	1.09	0.50	3.17
0.31-1.99	1.79	4.27	1.19	0.89	0.69	4.96	4.76	0.89	19.44
2.00-3.99	0.40	3.47	1.09	0.50	0.40	7.54	1.69	0.40	15.48
4.00-5.99	0.50	1.98	0.89	0.00	0.60	8.73	1.19	0.20	14.09
6.00-7.99	0.00	2.58	0.89	0.20	0.20	8.53	0.79	0.00	13.19
8.00-9.99	0.00	1.49	0.20	0.30	0.10	5.36	1.19	0.10	8.73
10.00-20.99	0.00	6.25	0.79	0.00	0.00	14.58	4.27	0.00	25.89
COLUMN SUMS	3.17	20.44	5.26	1.88	1.98	50.20	14.98	2.08	100.00

RESULTANT CURRENT IS 2.90 cm.s^{-1} AT 242° FROM NORTH

MEAN CURRENT IS 6.58 cm.s^{-1}

MAXIMUM CURRENT IS 20.70 cm.s^{-1}

TOTAL NUMBER OF READINGS 1008

PERSISTENCE IS 0.44

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 4.9 m FROM BOTTOM IN 9.8 m OF WATER

TABLE 1.17

LOCATION CODE : 1260

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Oct 75

LATITUDE : 79 24 09 W

LONGITUDE : 43 37 48 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.29	0.29	0.20	0.09	0.13	0.20	0.20	0.11	1.52
0.31-1.99	0.54	2.04	1.55	0.31	0.65	2.60	1.77	0.31	9.77
2.00-3.99	0.81	3.65	1.99	0.52	0.49	7.62	4.05	0.58	19.71
4.00-5.99	0.29	2.98	1.05	0.11	0.31	8.49	3.45	0.16	16.85
6.00-7.99	0.20	2.46	0.63	0.09	0.11	8.92	2.78	0.09	15.28
8.00-9.99	0.07	1.25	0.25	0.11	0.11	7.80	2.51	0.04	12.14
10.00-25.99	0.13	1.99	0.47	0.09	0.09	16.94	4.97	0.04	24.73
COLUMN SUMS	2.33	14.67	6.14	1.32	1.90	52.55	19.74	1.34	100.00

RESULTANT CURRENT IS 4.55 cm.s^{-1} AT 243° FROM NORTH

MEAN CURRENT IS 7.06 cm.s^{-1}

MAXIMUM CURRENT IS 25.05 cm.s^{-1}

TOTAL NUMBER OF READINGS 4464

PERSISTENCE IS 0.64

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 4.9 m FROM BOTTOM IN 9.8 m OF WATER

TABLE 1.18

LOCATION CODE : 1260

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Nov 75

LATITUDE : 79 24 09 W

LONGITUDE : 43 37 48 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES) 337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	0.00	0.25	0.00	0.00	0.00	0.06	0.12	0.25	0.68
0.31-2.99	0.98	3.26	2.21	0.68	0.31	5.41	4.37	1.41	18.63
3.00-5.99	0.92	3.20	2.34	0.37	0.43	12.30	6.03	0.31	25.89
6.00-8.99	0.25	1.11	0.25	0.00	0.12	8.43	5.23	0.43	15.81
9.00-11.99	0.00	0.31	0.06	0.06	0.25	8.92	4.31	0.06	13.96
12.00-14.99	0.00	0.00	0.00	0.00	0.00	8.55	3.87	0.00	12.42
15.00-40.99	0.00	0.00	0.00	0.06	0.00	8.49	4.06	0.00	12.61
COLUMN SUMS	2.15	8.12	4.86	1.17	1.11	52.15	27.98	2.46	100.00

RESULTANT CURRENT IS 7.09 cm.s^{-1} AT 244° FROM NORTH

MEAN CURRENT IS 8.37 cm.s^{-1}

MAXIMUM CURRENT IS 40.39 cm.s^{-1}

TOTAL NUMBER OF READINGS 1626

PERSISTENCE IS 0.85

READINGS TAKEN EVERY 10 min

INSTRUMENT WAS OPERATED 4.9 m FROM BOTTOM IN 9.8 m OF WATER

Ministry of the Environment
Ontario

TABLE 1.19

LOCATION CODE : 1290
AREA : Toronto Harbour
LAKE : Ontario

PERIOD : Sep 75
LATITUDE : 79 21 34 W
LONGITUDE : 43 38 05 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES)								
	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	2.78	1.39	0.20	0.99	3.17	4.96	1.98	0.99	16.47
0.31-1.99	7.14	2.38	0.79	0.60	2.78	13.10	7.94	3.37	38.10
2.00-3.99	1.98	0.99	0.99	0.00	1.59	9.72	12.30	1.19	28.77
4.00-5.99	0.00	0.60	0.99	0.00	0.00	0.00	0.40	0.00	1.98
6.00-7.99	0.00	0.79	0.40	0.00	0.00	0.20	0.40	0.00	1.79
8.00-9.99	0.00	1.79	0.40	0.00	0.00	0.00	0.00	0.00	2.18
10.00-35.99	0.00	4.37	4.56	0.20	0.00	0.20	1.39	0.00	10.71
COLUMN SUMS	11.90	12.30	8.33	1.79	7.54	28.17	24.40	5.56	100.00

RESULTANT CURRENT IS 1.13 cm.s^{-1} AT 58° FROM NORTH

MEAN CURRENT IS 3.82 cm.s^{-1}

MAXIMUM CURRENT IS 35.59 cm.s^{-1}

TOTAL NUMBER OF READINGS 504

PERSISTENCE IS 0.30

READINGS TAKEN EVERY 20 min

INSTRUMENT WAS OPERATED 2.4 m FROM BOTTOM IN 7.9 m OF WATER

Ministry of the
Environment
Ontario

TABLE 1.20

LOCATION CODE : 1290

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Oct 75

LATITUDE : 79 21 34 W

LONGITUDE : 43 38 05 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES) 337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	2.02	1.88	1.16	1.70	3.23	15.32	3.14	3.09	31.54
0.31-2.99	2.51	3.99	2.11	0.99	3.36	16.26	11.56	3.85	44.62
3.00-5.99	0.27	1.61	0.99	0.13	0.54	4.30	5.91	0.27	14.02
6.00-8.99	0.04	0.58	0.49	0.04	0.09	0.40	2.46	0.04	4.17
9.00-11.99	0.04	0.18	0.13	0.09	0.04	0.31	0.85	0.00	1.66
12.00-14.99	0.00	0.00	0.13	0.04	0.00	0.09	0.54	0.00	0.81
15.00-38.99	0.00	0.13	0.49	0.04	0.00	0.36	2.15	0.00	3.18
COLUMN SUMS	4.88	8.38	5.51	3.05	7.26	37.05	26.61	7.26	100.00

RESULTANT CURRENT IS 1.40 cm.s^{-1} AT 250° FROM NORTH

MEAN CURRENT IS 2.52 cm.s^{-1}

MAXIMUM CURRENT IS 38.97 cm.s^{-1}

TOTAL NUMBER OF READINGS 2232

PERSISTENCE IS 0.56

READINGS TAKEN EVERY 20 min

INSTRUMENT WAS OPERATED 2.4 m FROM BOTTOM IN 7.9 m OF WATER

TABLE 1.21

LOCATION CODE : 1290

AREA : Toronto Harbour

LAKE : Ontario

PERIOD : Nov 75

LATITUDE : 79 21 34 W

LONGITUDE : 43 38 05 N

FREQUENCY TABLE

	DIRECTION COMING FROM (DEGREES)								
SPEED (cm.s^{-1})	337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	1.76	0.32	0.32	0.88	5.28	17.41	2.96	5.14	34.07
0.31-2.99	1.76	3.43	1.11	1.16	3.89	11.76	6.20	2.82	32.13
3.00-5.99	0.05	1.90	1.62	0.60	0.88	4.31	7.59	0.37	17.31
6.00-8.99	0.23	0.14	1.06	0.05	0.00	1.25	3.15	0.00	5.88
9.00-11.99	0.00	0.14	0.14	0.05	0.00	0.60	2.13	0.00	3.06
12.00-14.99	0.05	0.05	0.19	0.05	0.00	0.42	1.16	0.09	1.99
15.00-39.99	0.19	0.00	0.32	0.05	0.05	0.46	4.03	0.46	5.56
COLUMN SUMS	4.03	5.97	4.77	2.82	10.09	36.20	27.22	8.89	100.00

RESULTANT CURRENT IS 2.38 cm.s^{-1} AT 253° FROM NORTH

MEAN CURRENT IS 3.58 cm.s^{-1}

MAXIMUM CURRENT IS 39.70 cm.s^{-1}

TOTAL NUMBER OF READINGS 2160

PERSISTENCE IS 0.67

READINGS TAKEN EVERY 20 min

INSTRUMENT WAS OPERATED 2.4 m FROM BOTTOM IN 7.9 m OF WATER

Ministry of the Environment
Ontario

TABLE 1.22

LOCATION CODE : 1290
AREA : Toronto Harbour
LAKE : Ontario

PERIOD : Dec 75
LATITUDE : 79 21 34 W
LONGITUDE : 43 38 05 N

FREQUENCY TABLE

SPEED (cm.s^{-1})	DIRECTION COMING FROM (DEGREES) 337.50 - 22.49	22.50 - 67.49	67.50 - 112.49	112.50 - 157.49	157.50 - 202.49	202.50 - 247.49	247.50 - 292.49	292.50 - 337.49	ROW SUMS
0.0-0.30	1.26	0.46	0.23	0.80	2.17	11.43	0.69	1.37	18.40
0.31-2.99	2.86	5.49	1.83	1.71	3.09	13.14	3.54	3.20	34.86
3.00-5.99	0.11	2.29	2.17	1.83	0.57	8.11	8.57	0.34	24.00
6.00-8.99	0.00	1.60	1.14	0.00	0.00	3.43	7.31	0.00	13.49
9.00-11.99	0.00	0.00	0.00	0.23	0.00	1.03	1.49	0.00	2.74
12.00-14.99	0.00	0.00	0.00	0.11	0.00	0.57	0.69	0.00	1.37
15.00-39.99	0.00	0.00	0.00	0.00	0.00	0.69	4.46	0.00	5.14
COLUMN SUMS	4.23	9.83	5.37	4.69	5.83	38.40	26.74	4.91	100.00

RESULTANT CURRENT IS 2.84 cm.s^{-1} AT 249° FROM NORTH

MEAN CURRENT IS 4.17 cm.s^{-1}

MAXIMUM CURRENT IS 39.98 cm.s^{-1}

TOTAL NUMBER OF READINGS 875

PERSISTENCE IS 0.68

READINGS TAKEN EVERY 20 min

INSTRUMENT WAS OPERATED 2.4 m FROM BOTTOM IN 7.9 m OF WATER

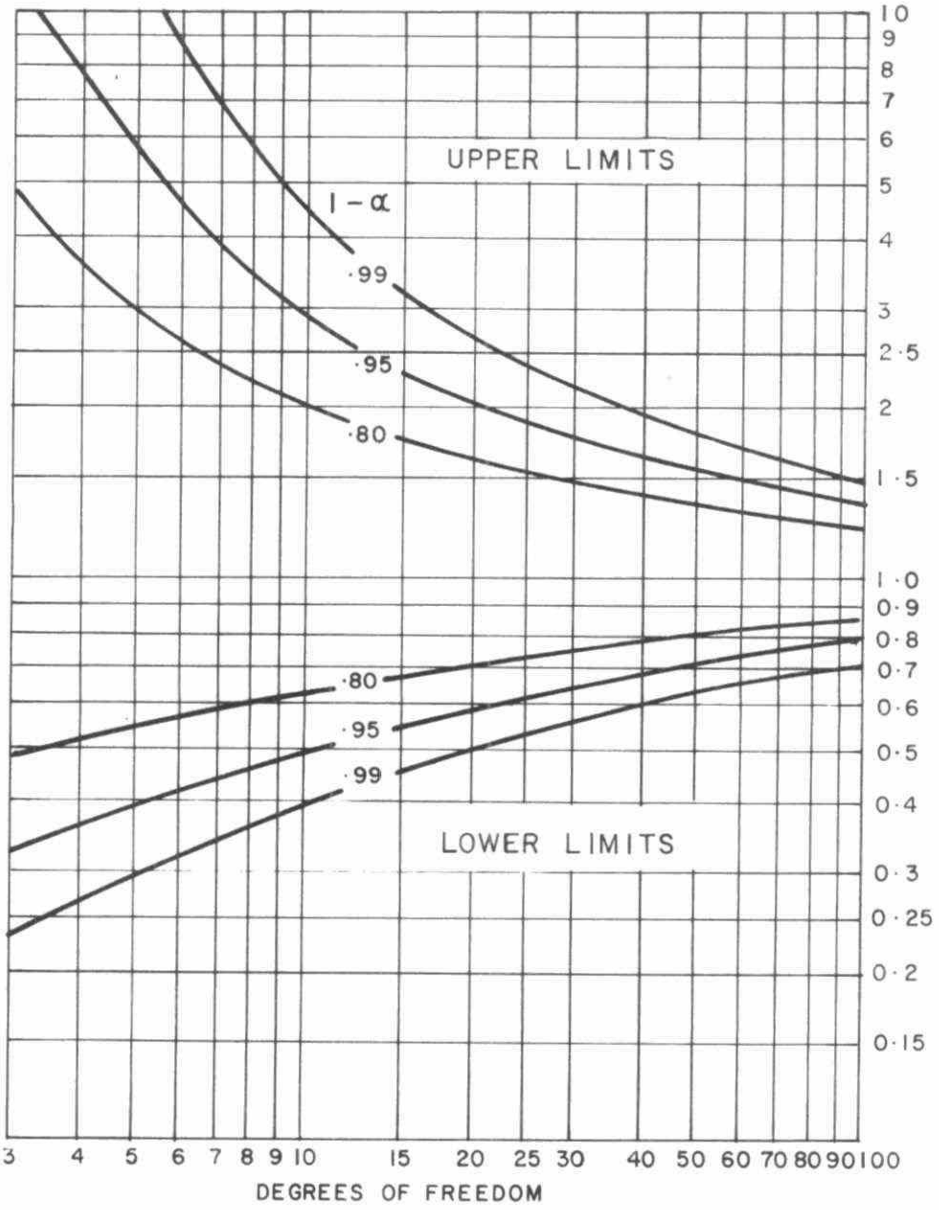

FIG. 1·01 : UPPER AND LOWER LIMITS OF CONFIDENCE FOR SPECTRA
(After Jenkins And Watts, 1969)